Estimating radio range

By Harold Kinley, C.E.T.

Many variables go into the formula for calculating radio coverage area or range. Unlike free-space propagation, no simple formula fits every situation for plane-earth propagation. Of particular importance in estimating or calculating radio coverage is the terrain itself or the "lay of the land." In this column we will look at a series of range prediction graphs based on the modified Egli model—a formula found in Edward Singer's book, *Land Mobile Radio Systems* (Prentice-Hall, 1989).* This book is highly recommended for anyone working in land mobile radio.

* This book is now in its second edition, published in 1994.

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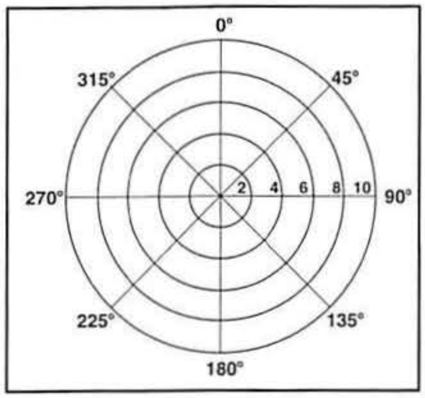

Figure 1. The intersections of cardinal radials from a tower site and concentric circles of a set increment are used as sampling locations for determining height above average terrain (HAAT).

Before describing the use of these graphs, let's cover a few topics that you should know and understand to better use the graphs.

Effective base antenna height

To calculate the "effective" antenna height or height above average terrain (HAAT) for a base antenna, three figures must be known or computed:

(1) the height of the antenna above ground level (AGL).

(2) the elevation of the tower site above sea level (ASL).

(3) the average terrain elevation above sea level.

To calculate the average terrain elevation, you must know the elevation at the tower site and at 40 points surrounding the tower site. Figure 1 at the left shows the required locations where the elevation must be known. The center is the tower site location. Notice that there are eight radials extending from the center to a point 10 miles out. These radials begin at 0° and are spaced 45° apart. They are known as the *cardinal* radials. Concentric circles at two-mile increments are drawn around the center point, with the outer circle being at a distance of 10 miles from the tower or center. At each point where a radial intersects a circle, the elevation must be determined.

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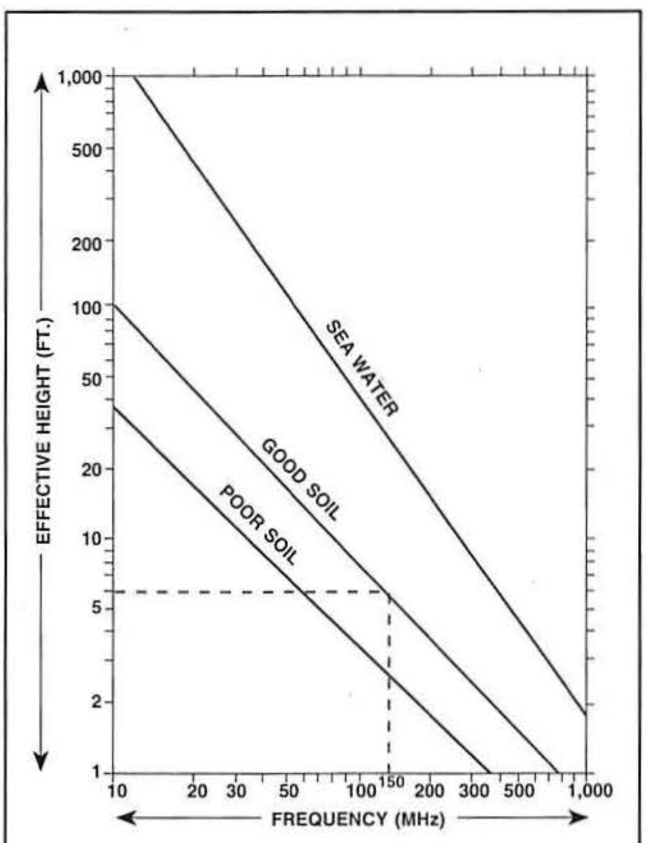


Figure 2. The effective height of a mobile antenna depends on the conductivity of the soil or other surface. Note that at 150MHz the minimum effective height is approximately 6 feet.

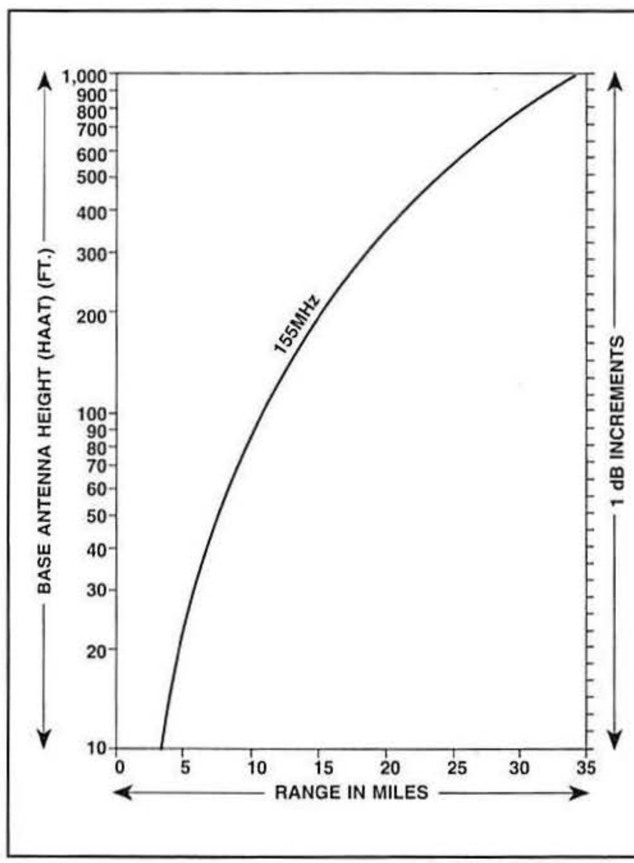


Figure 3. This is a graph of range vs. tower height for 155MHz with an effective radiated power (ERP) of 100W. The complete set of operating characteristics is: ERP = 100W; gain of mobile antenna = −1dBd; receiver line loss = 1.5dB; noise degradation = 3dB; receiver antenna height = 6 feet; probability of communication = 90%.

(continued from page 8)

A transparency of Figure 1 can be made to fit the scale of a topographic map and can be used as an overlay to determine the elevation of the various points required for calculating average terrain elevation. The tower site or center point is used eight times in the calculations, once for each radial, so it carries more weight than the other points on the radials. Once the elevation at each of the points is determined, they are added together. Then the sum is divided by 48 to yield the *average terrain elevation.*

Once the average terrain elevation is determined, the HAAT, or effective antenna height, is determined by adding the antenna tower height above ground level (AGL) to the tower site elevation above sea level (ASL), then subtracting the average terrain elevation. The step-by-step process is shown in the table on page 48.

Effective mobile antenna height

For mobile antennas, a factor known as *minimum effective height* must be considered. The graph in Figure 2 on page 8 provides an approximation of the minimum effective mobile antenna height over *poor soil, good soil* and *sea water.* The dashed lines indicate that the minimum effective height of a mobile antenna at 150MHz is approximately 6 feet. The minimum effective height should be used for calculations if it is greater than the *actual* height of the mobile antenna. If the actual height of the mobile antenna is greater than the minimum effective height, then the actual height should be used.

Antenna gain figures

When using various formulas involving propagation and path loss, the *reference antenna* for the antenna gain figures must be clearly understood. A lossless halfwave dipole has a gain of 2.15dB over the isotropic radiator (a theoretical antenna with equal radiation in all directions). When the isotropic radiator is used as the reference, the gain should be stated in *dBi.* When the halfwave dipole is used as the reference, the gain should be stated in *dBd.*

Mobile antennas usually are referenced to the quarterwave mobile antenna. Compared to a halfwave dipole, the quarterwave mobile antenna would have a gain of about −1dBd.

Effective radiated power

The term effective radiated power (ERP) takes into consideration any losses or gains in the system between the transmitter output and the antenna (including antenna gain). It is easier to work with dBm or dBW units of measure because line losses and antenna gains are usually given in dB. To convert transmitter output to dBW, use the following formula:

$$\text{dBW} = 10\log P \qquad [1]$$

To convert dBW back to power in watts use this formula:

$$\text{watts} = \text{antilog}\,(\text{dBW}/10) \qquad [2]$$

As an example, suppose that a transmitter has an output of 100W, a transmission line loss of 2dB and an antenna gain of 5dBd. The transmitter output in dBW is:

$$\begin{aligned}\text{dBW} &= 10\log(100)\\ &= 10(2)\\ &= 20\text{dBW}\end{aligned}$$

The effective radiated power is:

$$20dBW - 2dB + 5dB = 23dBW$$

The ERP in watts is found from:

$$\begin{aligned} \text{watts} &= \text{antilog}(dBW/10) \\ &= \text{antilog}(23/10) \\ &= \text{antilog}(2.3) \\ &= 199.5W \end{aligned}$$

Noise degradation

If the mobile unit is operating in a heavily industrialized area, the noise level probably will cause significant degradation of the signal. That is, a higher signal level will be required to produce a given level of quieting or a given SINAD ratio from the receiver. The noise problem is less severe at VHF highband than on VHF lowband. As the operating frequency increases, the noise problem decreases.

According to *Electronic Communications Handbook* (1988 McGraw-Hill), the noise degradation in suburban residential New York is 10dB at 150MHz, 6dB at 450MHz and 0dB at 900MHz. In rural areas, the noise degradation would be much less: 2dB or 3dB or even less in extremely quiet areas. One noise factor is the ignition noise coming from the vehicle itself. This is one noise source that the mobile receiver cannot avoid. It can greatly degrade reception even at VHF highband frequencies.

Reliability ratio

To improve the reliability or probability of communications, a fade margin or reliability margin must be built into any formula for calculating radio coverage area or range. Higher probability factors require greater reliability ratios or fade margins in decibels. In the following graphs of radio communications range, the probability of communication is 90%. The reliability ratios are: 14dB for VHF

	DISTANCE FROM TOWER IN MILES					
RADIAL AZIMUTH	0	2	4	6	8	10
0°	690	600	650	625	670	700
45°	690	570	590	615	650	625
90°	690	600	615	690	710	640
135°	690	625	640	675	700	680
180°	690	700	750	725	730	740
225°	690	680	680	690	640	650
270°	690	710	700	690	725	740
315°	690	710	740	750	710	700
TOTALS	5,520 (A)	5,195 (B)	5,365 (C)	5,460 (D)	5,535 (E)	5,475 (F)

(1) Add column totals (A) through (F) = 32,550
(2) Average terrain = step (1) ÷ 48 = 678.125
(3) Tower site elevation = 690
(4) Antenna height = 500
(5) HAAT = (3) + (4) − (2) = 511.875

Table 1. Step-by-step process for determining height above average terrain.

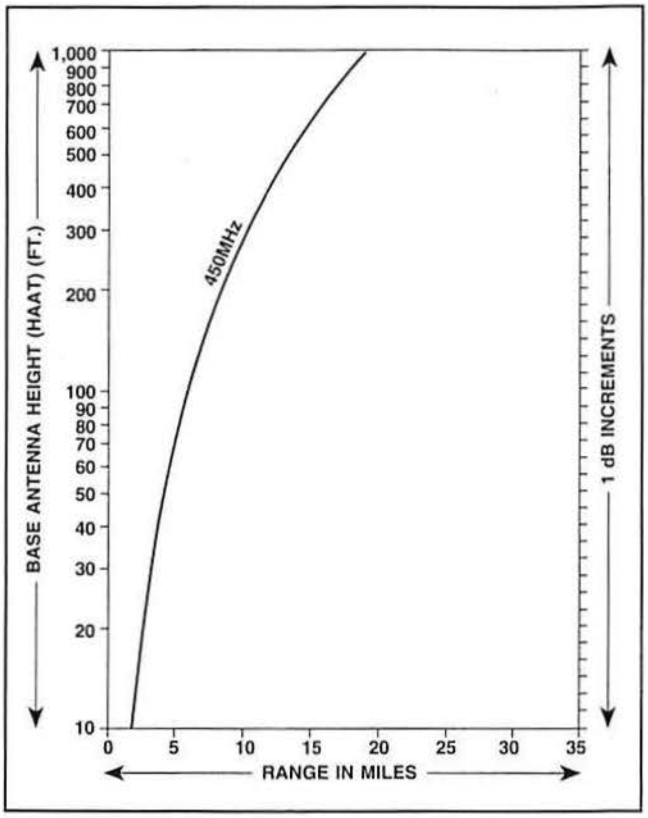


Figure 4. This is a graph of range vs. tower height for 450MHz with an effective radiated power (ERP) of 100W. The complete set of operating characteristics is: ERP = 100W; gain of mobile antenna = −1dBd; receiver line loss = 1.5dB; noise degradation = 1dB; receiver antenna height = 6 feet; probability of communication = 90%.

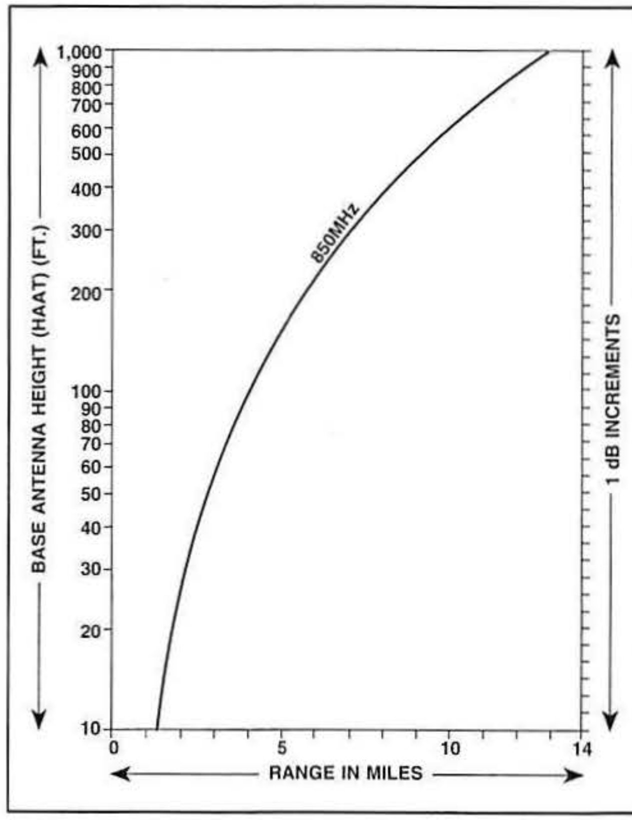


Figure 5. This is a graph of range vs. tower height for 850MHz with an effective radiated power (ERP) of 100W. The complete set of operating characteristics is: ERP = 100W; gain of mobile antenna = −1dBd; receiver line loss = 1.5dB; noise degradation = 0dB; receiver antenna height = 6 feet; probability of communication = 90%.

highband, 17dB for UHF and 19dB for 850MHz.

Radio coverage graphs

The graphs of radio range are based on terrain data from the Eastern Seaboard and Central Plains states with gently rolling terrain and average hill heights of 50 feet.

Three graphs are presented: Figure 3 on page 8 for VHF highband (155MHz), Figure 4 above left for UHF (450MHz) and Figure 5 above right for 800MHz (850MHz). Because all of these graphs are similar, only one will be described here. The graph in Figure 3 is for VHF highband. The various characteristics are listed. If the characteristics you need to use differ from those listed for this graph, adjustments can be made using the vertical decibel scale at the right. For example, this graph is based on an effective radiated power

(ERP) of 100W. If the ERP you are using is different, simply apply the formula:

$$dB = 10\log(P/100) \qquad [3]$$

where

P = effective radiated power in watts.

This calculation yields a dB correction figure to apply to the graph. For example, if the ERP is 200W, a +3dB correction figure results from Formula 3. Here is how to apply the correction figure to the graph.

Suppose, in Figure 3, that the antenna height (HAAT) is 200 feet. According to the graph, the range for 100W ERP is approximately 15.3 miles. If the effective radiated power is 200W instead of 100W, the dB correction figure will be +3dB. To get the range for 200W ERP, move from the 200-foot point over to the right dB scale and up 3dB. Move back over to the graph and down to the horizontal range scale to find the new range of approximately 18.3 miles for the corrected ERP figure.

Corrections for different noise levels also can be applied the same way. Receiver sensitivity also can be adjusted this way. For example, the graph in Figure 3 is for a receiver sensitivity of 0.35V (12dB SINAD). If your receiver sensitivity is 0.7V, the correction factor would be:

$$\begin{aligned} dB &= 20\log(0.35/S) \\ &= 20\log(0.35/0.7) \\ &= 20\log(0.5) \\ &= 20(-0.3) \\ &= -6dB \end{aligned}$$

where

S = 12dB SINAD sensitivity in V.

Be sure to observe the value signs of the dB correction factors. Negative correction factors reduce the range, and positive correction factors increase the range.

Figure 3 shows that doubling the antenna height is equivalent to a 6dB change. This relationship means that the same effect can be achieved by using a higher-gain base antenna, using a higher-gain mobile antenna, using better transmission line to reduce line losses, increasing transmitter power, using receivers with better sensitivity or any combination of the above that results in a net increase of 6dB.

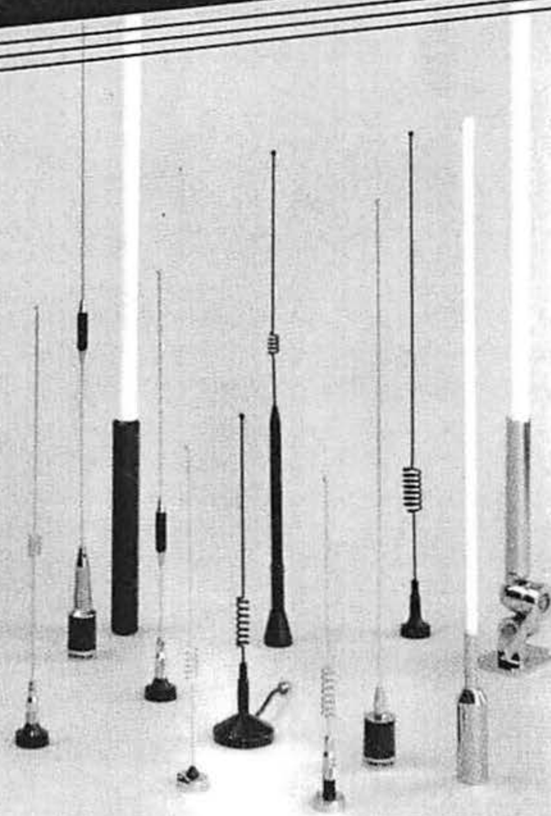
Figure 3 also shows that a 6dB increase boosts the range by about 40%. A 12dB increase extends the range by about 100%. For example, to increase the range by 40%, we could increase the antenna gain of the base station by 3dB and double the power (another 3dB increase).

Quadrupling the antenna height is equivalent to a 12dB change. This change is equal to increasing the transmitter power by a factor of 16. The increase in antenna height must be effective height or HAAT. For example, if the average terrain elevation is 750 feet, the antenna tower is 200 feet and the tower site elevation is 1,500 feet, then the HAAT is 1,500' + 200' − 750' = 950'. If the actual tower height is doubled (from 200 feet to 400 feet) the new effective height is: 1,500' + 400' − 750' = 1,150'. Thus, the *effective* height increased from 950 feet to 1,150 feet, much less than double. This change would result in only a slight improvement.

The graphs in Figures 4 and 5 are similar to the graph in Figure 3, but they are for 450MHz and 850MHz operations. Graphs such as these must be used cautiously and with two parts common sense! Even so, they are useful in making a determination of average coverages to be expected from given operating characteristics.

Computerized coverage plots

Computerized coverage plots have taken



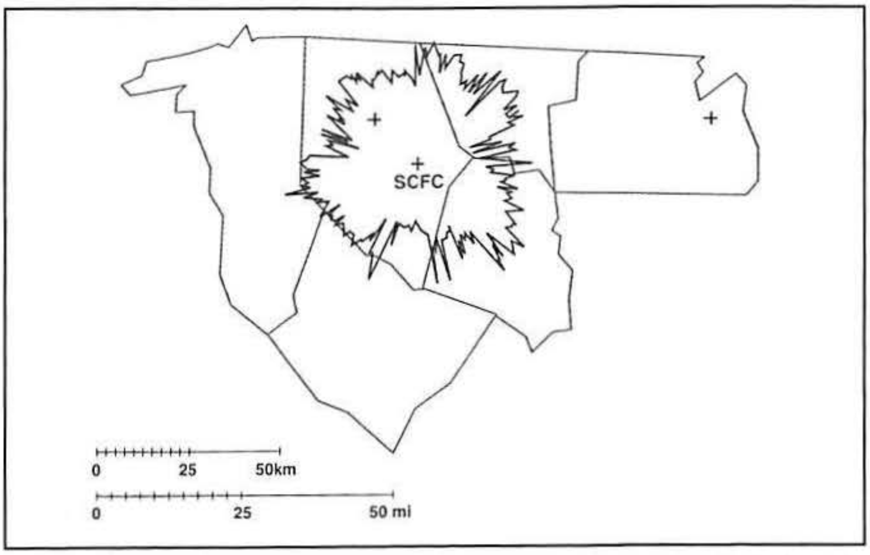


Figure 6. This radio coverage plot was produced with SoftWright's Terrain Analysis Package. The various terrain elevations are retrieved from a terrain database and the various elevations are computed for each point (at 0.1-mile increments) on each radial. This plot contained 360 radials. This contour is for 16dBu or 6.3μV/m. Considering a mobile antenna gain of −1dBd and a line loss of 1.5dB, this will produce slightly more than 1μV at the receiver input at 160MHz along the 16dBu contour.

much of the guesswork out of radio range calculation. Computer programs take into account effective radiated power, required signal level, probability of communications, terrain elevations, antenna height and other pertinent factors. Coverage plots can be printed on a dot matrix printer or a plotter with county-line boundaries included on the plot.

Figure 6 at the left shows a computer-generated contour plot prepared with SoftWright's Terrain Analysis Package software. This plot was prepared using 360 radials at 1° spacing. The incremental value on each radial was 0.1 mile. This plot provided a contour with excellent resolution. The signal level for this contour was 16dBu. At 160MHz, with a line loss of 1.5dB and a quarterwave mobile antenna, the signal level at the receiver input is slightly higher than 1μV.

Several computer programs that are useful in determining signal level, radio range, path loss, HAAT calculations and ERP calculations are available from the author. The cost is $10 plus $2.50 for shipping and handling. Please specify 3½-inch or 5¼-inch floppy disk. These programs are for IBM-compatible PCs running MS-DOS. Write to the author at 204 Tanglewylde Drive, Spartanburg, SC 29301-2949.

Stay tuned!

References

1. *VHF and UHF Propagation*, Datafile Bulletin 10003-1, General Electric, Lynchburg, VA, 1962.

2. Inglis, Andrew F., *Electronic Communications Handbook*, McGraw-Hill, New York, 1988.

3. Singer, Edward, *Land Mobile Radio Systems*, Prentice-Hall, Englewood Cliffs, NJ, 1989.